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WEATHERING EFFECTS OF NATURAL ORGANIC ACIDS AND ACID PRECIPITATION IN LABRADOR LAKES

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INLAND WATERS DIRECTORATE
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WATER QUALITY BRANCH
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Thomas A. Clair

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Environment Canada
Conservation and Protection Service
Inland Waters Directorate
Water Quality Branch
Box 861, Moncton, N.B.
E1C 8N6

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ABSTRACT

Thirty five lakes located in southern Labrador were sampled in 1989 as part of Environment Canada's acid precipitation monitoring program. Water chemistry values were compared to those from a similar sampling conducted in 1981. Results showed increases in pH, specific conductance, ANC, colour and base cations between the two dates, though sulfate, the ion most likely to reflect acid precipitation did not vary. The major ion changes are probably due to climatic variations, as river discharge amounts were much lower in 1989 than in 1981.

Results showed a slight but significant decrease in water sulfate concentration trend from western to eastern Labrador, though most values, even in the western portion of the study area fell close to the values considered "background" by Brakke et al. (1989). Assuming little accelerated weathering caused by acid precipitation in this region, and assuming that weathering exceeding that predicted from carbonato effects is due to natural organic acids, then mineral dissolution by natural organic acids ranges between 9 and 52% of the total.

RESUME

Trente-cinq lacs situés dans la section sud du Labrador, furent échantillonnés en 1989. Les valeurs recueillies furent comparées à celles mesurées dans les mêmes lacs en 1981. Les résultats ont démontrés des augmentations de pH, de conductivité spécifique, de capacité de neutralisation d'acide, de couleur et de cations de base entre les deux visites. Les valeurs de sulfate n'ont pas changées. Les différences entre les deux années furent probablement causées par des variations hydrologiques, et non par des changements causés par les pluies acides, car les conditions hydrologiques furent beaucoup plus sèches en 1989 qu'en 1981.

Les résultats de l'échantillonage ont aussi démontrés une legère diminution de concentration de sulfate de l'ouest à l'est du Labrador, mème si plusieures valeurs dans la partie ouest du territoire pouvaient être considérées comme étant des valeurs non-polluées selon les critères de Brakke et al. (1989). Etant donné la petite influence des pluies acides sur la dégradation du roc, la contribution par les acides organiques naturels aux cations de base aquatiques fut calculée comme étant entre 9 et 52% du total.

MANAGEMENT PERSPECTIVE

This study compares lake chemistry results from sampling trips conducted in southern Labrador in 1981 and 1989. Results show that there is no significant acidification of the lakes sampled, even though lakes in the western portion of the region have slightly higher sulfate concentrations than those in the eastern section. The results do show that hydrological conditions should be evaluated when attempting to determine whether trends in water chemistry have occurred.

As the data collected represented conditions from pristine sites, a method was worked out to calculate the importance of natural organic acids (humic substances) in determining the cation concentration of surface waters. These results showed that between 9 and 52% of cations measured in surface waters were probably produced by organic acid weathering of bedrock.

INTRODUCTION

Most freshwaters in the industrialized parts of the world have been affected by acid precipitation. Inadequate sampling and analysis has caused a lack of pre-pollution information making it difficult to understand geochemical processes affecting water quality at impacted sites. Pristine sites are needed as environmental controls to permit the clarification of natural phenomena obscured by conditions present in areas influenced by civilization. Pertinent questions include: 1) what background levels of sulfate (SO_4^{-2}) should be expected in pristine sites compared to those from industrial regions, 2) what is the importance of bedrock and soil composition on water chemistry, 3) what is the importance of dissolved organic carbon in weathering processes and acid-base properties of freshwaters.

Some of these concerns have been addressed in other studies. Brakke et al. (1989) studied data from a number of sites in the continental USA and Europe, and estimated background SO_4^{-2} values to range from 10 to 15 $\mu eq*L^{-1}$ in surface waters. Bedrock and soils strongly influence the freshwater major ion chemistry of freshwaters. Because of the presence of anthropogenic acids, it is often difficult to estimate natural weathering rates (Kilham 1982, Katz et al. 1985). Data from unpolluted areas however, should allow a better understanding of bedrock influences in determining background water chemistry.

Natural organic acids, as reflected by dissolved organic carbon (DOC) are an important component of freshwaters. The complexation of cations with DOC has been suggested to be important factor in weathering processes (Cronan 1985). As above however, the role of DOC

as a weathering agent is difficult to study in polluted regions, so it is useful to see if information from pristine sites can be used to clarify its role in mobilizing cations.

While lakes in Labrador are low in total dissolved ions (Duthie and Ostrofsky 1974, Jamieson 1974), studies previous to 1981 were restricted spatially and measured only a few chemical parameters. A survey of 42 lakes conducted in 1981 by the Water Quality Branch of Environment Canada (WQB) and the University of Minnesota (Clair et al. 1982) was designed to provide a more chemically and geographically comprehensive description of Labrador's water chemistry. In 1989, WQB resurveyed most of its original sites to see if changes in water chemistry had occurred over the intervening years. Recent work in the area (Scruton 1984) showed a west-east gradient in lake water SO_4^{-2} concentration, but as the parameter was measured using the colourimetric methyl thymol blue method (MTB) which overestimates SO_4^{-2} in highly coloured waters (Kerekes et al. 1984), the trend required confirmation.

The purpose of this work is to report on the chemistry from Environment Canada's Labrador lake survey sampled in the fall of 1989. The specific objectives of the study were i) to assess the chemistry of lake waters from Labrador in 1989 and compare results to those measured from the 1981 sampling program, ii) with high quality data, see if there are east-west differences in sulfate which would indicate acid precipitation effects, and iii) to understand the relative contributions of mineral versus organic weathering in areas receiving little or no mineral acid inputs.

STUDY AREA AND METHODS

Labrador is located on the extreme northeastern edge of North America (Figure 1). It is lightly populated, with approximately 29,000 people occupying nearly 280,000 km^2. The main industries are iron ore mining, fishing, trapping, hydroelectric power generation, and the maintenance of an armed forces base, so that little anthropogenic acidifying pollution is generated locally. The portion of Labrador which was sampled in 1989 was the southern part of the region, occupying approximately two thirds of the total territory. The maximum length from one end of the study area to the other is approximately 700 km.

The part of Labrador studied here typically receives between 1000 to 1100 mm of precipitation, of which only approximately 400 mm evaporates. The mean July temperature is 12.5°C (Hydrological Atlas of Canada 1978). Though no dependable precipitation chemistry data exist for most of the region, values from precipitation stations at Fermont and Schefferville in northeastern Quebec, near the western Labrador border show annual precipitation pH of 4.84 and 4.98 and SO_4^{-2} of 15.1 and 13.2 $\mu eq*L^{-1}$ (Boulet et Jacques 1989). The pH values are slightly lower than the 5.0 to 5.2 range considered to be background by Galloway et al (1982). It can be assumed that the areas in the eastern portion of the region receive even less anthropogenic sulfate.

The area is underlain in the western and southeastern portions mainly by Helikian gneisses and earlier granites (Newfoundland and Labrador Dept. of Mines 1975) and in the northeast by Helikian biotite-quartz, feldspar assemblages and Archean granites. Also scattered throughout the region are sandstone, evaporite and igneous formations which complicate the description of

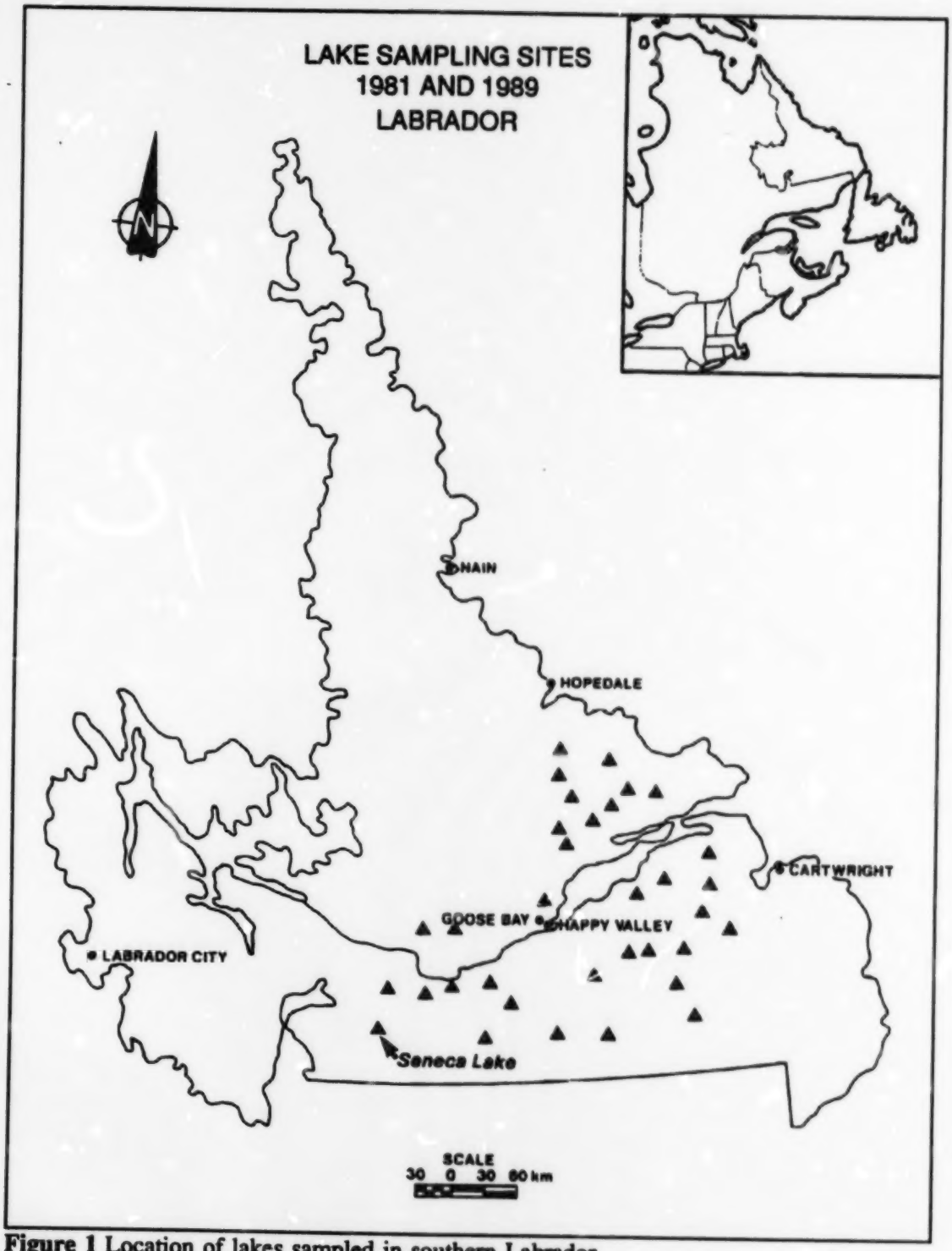

Figure 1 Location of lakes sampled in southern Labrador.

the area. Throughout most of the sampled area, soils are thin and poorly drained with Sphagnum bogs being commonplace throughout the southern part of the region (Lands Directorate 1977). Topography is generally flat in the southwest, and hilly in the southeast and northeast.

Samples in 1981 and 1989 were collected in August and September at approximately 0.3 m from the water surface. Thirty five sites were sampled in 1989 which were also sampled in 1981 (Figure 1). Table 1 shows the analytical methods used by the laboratory in 1981 and 1989. Sulfate analysis of samples collected in 1981 was done using the methyl thymol blue (MTB) method, a method shown to be inaccurate in highly coloured waters (Kerekes et al. 1984). However, in order to be able to compare concentrations in this variable between the two samplings, this method as well as the more precise ion chromatography method was again used on samples collected.

Table 1. Analytical methods used for the two samplings.

Parameter	Method	
	1981	1989
pH	Potentiometric	same
ANC	2 end point	Gran
colour	Visual (Hazen)	same
DOC	Infrared anal. High temp. combus.	Colourimetric wet oxidation
Chloride	Specific ion elec.	Ion Chromatog.(IC)
Sulfate	MTB	IC and MTB
Calcium	Atomic Absorp.(AA)	same
Magnesium	AA	same
Potassium	Flame photometry (emission)	same
Sodium	Flame photometry (emission)	same
Aluminum (extrac.)	AA	same
Manganese (extrac.)	AA	same
Iron (extrac.)	AA	same

Dissolved organic carbon contributes to the ion balance. Oliver et al (1983) calculated that on average, approximately 10 μeq of organic anion sites are generated per mg of organic C.

A number of studies (Howell and Pollock 1986, Kortelainen et al 1989) have found that the charge density of organic acids is only 50% of this calculated A^- value. Based on those studies, the organic anion concentration of samples was calculated as one half of the value given by the Oliver et al. (1983) approach. This modified concentration is denoted as A^{-*}.

A number of sites along the east coast of Labrador had elevated levels of Cl^-, suggesting a major ion component contributed by sea-spray from the nearby Labrador Sea. The data were normalized to remove this component using the sea-salt correction factor of Wat[illegible] et al. (1979). The 1989 sampling also included a random selection of sites for triplicate analyses.

Results and Discussion

Quality control procedures in the 1989 field sampling and laboratory analyses were monitored from five sets of replicate samples collected at sites randomly selected during the field work (Appendix A). Results of the analyses show good reproducibility in all parameters from all samples (<10%), except for the samples collected at site 01NF03QB0001, where SO_4^{-2}, Mg, K, and Na show greater variability. The values are at or near the analytical detection limits for the parameters and thus the greater variability is not indicative of sampling or analysis problems, and the results do not compromise the use of the samples in data analysis. Only two other parameters show variability >10%, Ca^{+2} for lake 01NF03PC0008, and K^+ for site 01NF03OE0005. Again the values were near detection levels and do not indicate serious problems. Only the triplicate sample with the median pH value was used in data interpretation. When all three pH values were similar, ANC was next used.

The 1989 data (Appendix B) show that these waters are very dilute compared to most elsewhere in North America (Brakke et al. 1989). ANC is low as are the sums of the base cations (C_b). This a result of the generally thin, poorly drained soils overlying resistant bedrock. At a number of sites, water chemistry actually resembled that of rain water. Nitrate values were all below detection levels of 0.5 $mg*L^{-1}$, and are thus neglected in the data analysis. Sulfate values generally fall near the range of 10 to 15 $\mu eq*L^{-1}$ estimated as being a reasonable background value by Brakke et al (1989).

In order to determine whether there was a change in chemistry over the last eight years, values from the 35 lakes (Appendices B,C) were compared using a T-test for paired sets of

Table 2. Mean variable values for each sampling data, along with numbers of pairs used, and results of paired T-test.

Parameter	Mean		n	Signif. Dif.
	1981	1989		@ 95%
H^{+1}	0.98	0.67	35	yes
ANC[1]	26.2	41.0	35	yes
colour[2]	35.9	52.2	35	yes
DOC[3]	6.65	6.35	35	no
C_b[1]	75.6	93.0	35	yes
Cl^{-1}	17.2	16.6	35	no
SO_4^{-2} [4]	39.1	38.6	26	no
Conduct.[5]	10.3	13.1	35	yes

[1] values in $\mu eq*L^{-1}$,[2] values in Hazen units, [3] values in $mg*L^{-1}$
[4] methyl thymol blue method, [5] $\mu S*cm^{-1}$.

samples. Table 2 shows the results of the comparisons for the different variables.

Results show that pH, the sum of base cations, specific conductance, ANC and colour, were greater in 1989 than in 1981. Chloride, SO_4^{-2} and DOC were not significantly different between the two years. The lack of change in Cl^- and SO_4^{-2} seems to indicate that the main inorganic components of both anthropogenic and natural deposition did not seem to vary between the two samplings. Care must be exercised in studying the Cl^- values, as the 1981 method produced lower detection limit values. Less than detection values were used as real numbers in

the calculation of trend. As the lower detection limits in 1981 would tend to bias the calculation it should be noted that because there was a lower mean chloride concentration in 1989 using censored data, it suggests that 1989 values were actually lower than the previous samplings'. However, the difference which could be calculated showed no significant differences.

All other parameters except DOC increased, suggesting that a hydrological mechanism controls the terrestrial contribution to water chemistry. To support this thesis, river discharge was compared for the Eagle River in central Labrador for 1981 and 1989. Results showed 1981 to be the wettest year on record (yearly mean discharge 354 m^3 sec^{-1} compared to 267m^3 sec^{-1} long term average), while the 1989 value was 282 m^3 sec^{-1}. This difference suggests that the drier conditions in 1989 probably led to more concentrated water chemistry than in 1981. No limnological information is available for these lakes, but most of them appeared to be shallow glacial scour lakes draining large, boggy watersheds. The differences measured in water chemistry can then probably be related to greater evaporation or less dilution in the study lakes.

As colour increased, it was expected that DOC also would, but this turned out not to be the case. The chemical nature of DOC may have been different between the two years. Clair et al. (1989) showed that the acid-base chemistry of DOC will change with time due to biological activity, even when DOC concentration themselves do not vary. This situation may also be applicable to colour.

The differences between the two data sets suggest that because of the increase in the ionic concentration of lake water, there was perhaps a reduction in anthropogenic acidification effects in southern Labrador between the two years, as the concentration factor discussed above probably was also in effect for SO_4^{-2}.

In Atlantic North America, much of the atmospheric acidifying substances are produced in the Great Lakes basin and along the eastern coast of the United States and are transported eastward by prevailing weather systems (Shaw 1979). This suggests that a trend of decreasing surface water SO_4^{-2} might be detected in the Labrador lakes, as no major local anthropogenic sources exist. In order to test this hypothesis, a point was arbitrarily chosen in southwestern Labrador, the part of the region closest to the known origin of acidifying chemicals. From Seneca Lake (Figure 1), distances were measured to each site sampled, and the distance was correlated to sea-salt corrected SO_4^{-2}. The distances ranged from 48 to 396 km (Appendix B).

Using all data, a slight negative correlation was calculated between distance and SO_4^{-2}; SO_4^{-2} = -0.02(distance in km) + 22.57 (R^2 = 0.19, significant at 99.9%). Four sites in central Labrador showed anomalous SO_4^{-2} values which were correlated with high levels of base cations indicating geological influences. When these were removed from the database, the correlation between distance and SO_4^{-2} changed to: SO_4^{-2} = -0.014(km) + 18.6, R^2 = 0.14, significant at the 97.2% level (n =31). When divided into two groups, one for sites closer than 200 km and those further than 280 km from Seneca Lake, no significant difference was measured between groups. These statistics indicate that there may be a slight acid precipitation effect on water chemistry in southwestern Labrador.

A number of other factors should also be considered in explaining the SO_4^{-2} trend. Geology and soil composition is not consistent between the regions and could be partly responsible for the trend. Another factor could be the seasalt correction calculation which is more important in the eastern portion of the area. Potential inaccuracies in this well accepted calculation (Watt et al 1981, Thompson 1982) could overestimate the correction, thus reducing

SO_4^{-2} concentrations. Nevertheless, considering the natural variability inherent in water chemistry, and considering that there is a gradient in SO_4^{-2} concentrations in precipitation in eastern North America, the trend measured is not surprising.

Despite a significant west-east SO_4^{-2} trend, lake values in the western lakes were so near background that anthropogenic acidification probably did not significantly affect the major ion chemistry of lakes in the region. The lake data were therefore studied to see if weathering processes driven by carbonic acids could be isolated from those of organic acids. The weathering of soils and bedrock is known to be dependant on the quality and quantity of precipitation. Schindler (1988) reported that based on stoichiometric considerations, the ANC to base cations $Ca^{+2}+Mg^{+2}$ (C_b) ratios in areas not subject to acid precipitation should be in the range 0.6 to 1.1, due to natural rock dissolution. These values decrease with increased weathering, which in many areas is due to acid deposition. When the ANC to C_b relationship was calculated using the data, the ratios showed values averaging 0.51, ranging from 0.76 to 0.33, thus suggesting a source of weathering not accounted for by simple carbonato processes.

As anthropogenic acidification was shown not to be a serious problem at these sites, a portion of the weathering was proposed to be due to natural organic acids. This was tested by regressing the calculated ANC/C_b values with water colour which showed a significant correlation ($-0.0024(Colour) + 0.682$, $R^2 = 0.47$, significant at 99.9% confidence). To compensate for potential natural organic anion effect in weathering, the equation was modified to include the organic anion contribution, ie $(ANC+A^{-*})/C_b$. The mean ligand to C_b ratio was 0.85, with a range of 1.11 to 0.62, now falling within the range expected for non-polluted conditions.

In order to determine the organic anion contribution to base cation weathering, the

difference between the two weathering relationships was calculated. The average A^{-*} effect contributed 32% to C_b, with values ranging from 9 to 52 %. These results confirm that natural organic anions can significantly contribute to the chemistry of freshwaters and are thus important in weathering processes. The use of base cation/ANC ratios without including organic acid effects to describe acidification weathering effects is thus somewhat questionable if organic anions are not taken into consideration.

In Nova Scotia, where the DOC range is similar to that of southern Labrador, a positive correlation was found between DOC and Fe and Al in surface waters (Clair and Komadina 1983, Freedman and Clair 1987). This relationship did not prevail with the Labrador data where total extractable Fe ranged from 0.008 to 0.72 $mg*L^{-1}$ and Al from 0.02 to 0.18 $mg*L^{-1}$. The causes for this difference could be due to bedrock or chemical reactivity of DOC between areas.

With current field data, it is impossible to determine if the complexed cations were weathered directly from bedrock by H^+ dissociated from organic acids, or if they were dissolved into the water by carbonic acid action, and then complexed to DOC, though the acid with the lower pK_a would have supplied the hydrogen ion. Further studies comparing weathering rates in both clear and brownwater basins should be conducted to test this hypothesis, but it is quite likely that a combination of the two processes actually determines the final result in natural situations (Krumbein and Dyer 1985).

CONCLUSIONS

Results of this work indicate that a number of factors must be taken into account when comparing parameter values from lake surveys conducted at periodic intervals. The importance of hydrological conditions can be seen. Trends in acidification of surface waters must be placed in the context of normal year to year variability. Based on the data presented here, it seems that most lakes in southern Labrador have SO_4^{-2} concentrations at the background values identified by Brakke et al. (1989) and have not changed between 1981 and 1989. The differences in parameter values between 1981 and 1989 are most likely due to variability in climate. Weather data suggest that a concentration effect has taken place which would explain the higher cation and colour conditions in lake waters.

Analysis of Labrador lakes allowed an assessment of the impact of DOC in the weathering process. If the natural organic contribution were not taken into account, ion ratio values would suggest that the lakes were subject to acid precipitation. Taking into account the DOC contribution, it can be seen that organic acids, as expected, are partly responsible for the inorganic ion chemistry of lake waters. Use of ion ratios in areas more exposed to anthropogenic acidification should be done taking this factor into consideration.

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Appendix A

Replicates samples collected during the sampling program in 1989. All values are in $\mu eq*L^{-1}$, except for pH, colour (Hazen units) and DOC ($mg*L^{-1}$).

STA. #	pH	ANC	SO4	Cl	Ca	Mg	K	Na	DOC	COL
OE0005	6.2	41	17	11.3	55	31.3	3.1	13.1	6.0	70
OE0005	6.2	41	19	11.3	50	26.3	1.3	17.4	5.8	70
OE0005	6.2	39	17	11.3	50	28.8	1.3	17.4	5.2	70
PC0001	6.0	43	17	11.3	70	22.2	4.6	34.8	9.8	120
PC0001	6.0	43	17	11.3	70	26.3	5.6	39.2	9.2	120
PC0001	6.0	43	19	11.3	70	26.3	4.3	39.2	9.1	120
PC0008	6.4	38	10	36.7	45	17.3	3.6	39.2	3.5	25
PC0008	6.4	33	13	36.7	45	17.3	3.8	39.2	3.6	25
PC0008	6.4	34	13	22.6	45	17.3	3.3	39.2	3.5	25
QB0001	6.5	30	10	11.3	30	4.1	2.6	26.1	0.6	L5
QB0001	6.5	26	19	11.3	30	10.7	1.3	13.1	0.6	L5
QB0001	6.5	26	13	11.3	30	8.2	1.3	8.7	0.7	L5
QC0026	6.7	105	17	11.3	100	54.3	0.05	26.1	6.0	70
QC0026	6.6	108	17	11.3	95	49.4	0.10	26.1	6.0	70
QC0026	6.7	103	17	11.3	100	58.4	0.05	21.8	5.8	70

Appendix B

Parameter values from Labrador sites in 1989.

STATION	pH	DOC mg/L	COLOUR Hazen	A^{-*} µeq/L	ANC µeq/L	SO_4^{-2} µeq/L
WB0002	6.6	4.7	35	18.3	64.0	29.1
XA0006	6.2	5.5	50	20.6	27.9	14.6
XA0007	6.0	4.9	30	17.9	13.1	18.7
XA0008	6.4	6.9	55	26.1	50.8	22.9
XA0010	5.8	6.5	60	23.3	18.0	18.7
XA0011	6.0	8.8	90	32.6	36.1	20.8
XB0001	6.5	5.5	50	21.0	54.1	35.4
XC0001	6.0	8.8	100	32.6	34.4	16.6
NG0020	6.2	4.7	30	17.8	23.0	20.8
NG0021	6.2	4.0	20	15.0	18.0	18.7
OE0002	6.6	5.0	30	19.2	59.0	12.5
OE0004	6.4	5.9	40	22.3	42.6	14.6
OE0005	6.2	7.5	70	28.1	41.0	16.6
OE0006	6.4	4.8	35	18.5	39.4	16.6
OE0007	6.6	6.3	50	24.5	62.3	25.0
PB0001	6.5	10.4	60	39.7	64.0	25.0
PB0014	5.8	11.5	110	41.2	31.2	12.5
PC0001	6.0	12.2	120	45.0	42.6	16.6
PC0002	6.0	4.5	35	16.5	23.0	12.5
PC0003	5.6	8.9	110	30.9	19.7	16.6
PC0004	5.8	6.9	60	24.6	21.3	18.7
PC0006	6.2	7.4	65	27.6	42.6	14.6
PC0008	6.4	4.4	25	16.6	34.4	12.5

PC0010	6.3	4.0	25	15.1	31.2	14.6
QB0001	6.5	0.9	4	3.3	26.2	12.5
QB0002	6.4	1.2	4	4.8	21.3	12.5
QC0017	6.7	3.5	15	13.5	67.2	16.6
QC0019	6.0	6.3	35	22.9	23.0	12.5
QC0023	6.3	11.4	120	42.9	55.8	12.5
QC0024	6.1	7.5	45	27.8	31.2	22.9
QC0025	6.5	6.4	70	24.4	59.0	22.9
QC0026	6.7	7.5	70	29.0	105.0	16.6
QC0027	6.2	6.4	50	23.9	32.8	18.7
QC0028	6.7	4.9	20	18.9	85.3	16.6
QC0029	6.5	6.1	40	23.4	52.5	10.4

STATION	Cl µeq/L	Ca µeq/L	Mg µeq/L	K µeq/L	Na µeq/L	Dist. km
WB0002	L11.3	79.8	35.4	5.4	17.4	48
XA0006	L11.3	42.9	19.8	3.8	13.1	102
XA0007	L11.3	28.9	13.2	2.8	8.7	85
XA0008	L11.3	79.8	30.5	4.9	21.8	133
XA0010	L11.3	49.9	22.2	3.8	13.1	198
XA0011	L11.3	69.9	26.3	3.8	21.8	192
XB0001	L11.3	84.8	31.3	4.4	13.1	228
XC0001	L11.3	59.9	23.9	3.6	21.8	325
NG0020	31.0	47.4	22.2	4.9	39.2	347
NG0021	70.5	45.4	23.9	3.6	69.6	372
OE0002	L11.3	54.9	30.5	4.9	21.8	152
OE0004	L11.3	47.4	23.9	4.4	21.8	182
OE0005	L11.3	54.9	31.3	3.1	13.1	147
OE0006	L11.3	45.4	24.7	3.1	13.1	127
OE0007	33.8	64.9	35.4	4.1	21.8	167
PB0001	L11.3	74.9	28.8	10.2	30.5	247
PB0014	L11.3	64.9	22.2	2.8	26.1	308
PC0001	L11.3	69.9	22.2	4.6	34.8	300
PC0002	L11.3	32.9	15.6	5.9	43.5	334
PC0003	L11.3	42.4	19.8	3.8	30.5	331
PC0004	L11.3	32.9	17.3	2.6	26.1	364
PC0006	33.8	49.4	22.2	5.4	52.2	370
PC0008	22.6	46.9	17.3	3.3	39.2	385
PC0010	33.8	38.4	17.3	4.1	39.2	378
QB0001	L11.3	30.4	8.2	1.3	8.7	348
QB0002	28.2	25.4	15.6	1.3	26.1	323
QC0017	L11.3	59.9	31.3	1.3	17.4	300

QC0019	L11.3	28.9	19.8	1.3	26.1	382
QC0023	22.6	84.8	40.3	1.3	34.8	383
QC0024	L11.3	28.9	26.3	1.3	52.2	396
QC0025	L11.3	69.9	36.2	1.3	21.8	246
QC0026	L11.3	99.8	54.3	1.3	26.1	286
QC0027	L11.3	49.4	22.2	2.8	13.1	316
QC0028	L11.3	89.8	44.4	3.1	21.8	334
QC0029	L11.3	54.9	38.7	3.6	21.8	362

Appendix C

Parameter values from Labrador sites in 1981.

STATION	pH	DOC mg/L	COLOUR hazen	A^{-*} µeq/L	ANC µeq/L	SO_4^{-2} µeq/L
WB0002	6.5	3.4	20	32.5	36.1	43.7
XA0006	6.1	6.0	35	55.6	16.4	37.4
XA0007	5.9	4.5	20	40.8	9.8	31.2
XA0008	6.6	7.0	20	67.3	44.3	41.6
XA0010	5.5	7.0	40	59.9	16.4	37.4
XA0011	6.5	7.5	40	71.7	42.6	43.7
XB0001	6.1	6.0	30	55.6	16.4	37.4
XC0001	5.9	8.5	50	77.1	59.0	41.6
NG0020	6.1	7.5	20	69.5	29.5	37.4
NG0021	5.5	4.5	4	38.5	7.5	37.4
OE0002	6.1	8.8	30	81.6	23.0	31.2
OE0004	6.0	7.1	25	65.1	18.0	
OE0005	6.3	11.0	80	103.7	29.5	47.8
OE0006	6.4	7.5	10	71.3	29.5	37.4
OE0007	6.6	6.5	30	62.5	54.1	41.6
PB0001	6.1	7.0	20	64.9	45.9	37.4
PB0014	5.6	8.5	65	73.9	9.8	41.6
PC0001	6.0	9.0	80	82.6	16.4	47.8
PC0002	6.0	8.0	30	73.4	14.8	31.2
PC0003	5.6	10.0	110	87.0	8.2	47.8
PC0004	5.5	9.5	70	81.3	8.2	41.6
PC0006	6.0	7.0	40	64.2	19.7	37.4
PC0008	6.3	4.0	4	37.7	18.0	27.0

PC0010	6.1	5.5	20	51.0	21.3	31.2
QB0001	6.4	2.5	4	23.8	19.7	18.7
QB0002	6.8	1.0	4	9.7	31.2	20.8
QC0017	6.7	2.5	5	24.2	42.6	47.8
QC0019	5.9	12.0	80	108.9	21.8	31.2
QC0023	6.1	13.0	100	120.5	41.0	58.2
QC0024	5.8	5.0	30	44.8	8.2	41.6
QC0025	6.7	1.5	15	14.5	52.5	37.4
QC0026	6.8	5.5	25	53.4	45.9	37.4
QC0027	6.4	5.5	30	52.3	26.2	31.2
QC0028	6.2	7.5	40	70.2	27.9	31.2
QC0029	6.6	5.5	30	52.9	32.8	37.4

STATION	Cl µeq/L	Ca µeq/L	Mg µeq/L	K µeq/L	Na µeq/L
WB0002	8.5	66.4	29.6	2.6	30.5
XA0006	L2.8	33.9	14.0	2.6	21.8
XA0007	L2.8	22.5	10.7	5.1	21.8
XA0008	5.6	64.9	27.2	5.1	26.1
XA0010	8.5	44.9	18.1	7.7	21.8
XA0011	5.6	59.9	28.8	2.6	30.5
XB0001	8.5	32.9	18.9	5.1	21.8
XC0001	11.3	39.9	17.3	2.6	21.8
NG0020	33.8	40.9	17.3	5.1	43.5
NG0021	45.1	26.9	13.2	2.6	43.5
OE0002	11.3	37.4	22.2	5.1	21.8
OE0004	5.6	29.9	17.3	2.6	17.4
OE0005	16.9	44.9	28.8	2.6	30.5
OE0006	5.6	38.4	22.2	2.6	26.1
OE0007	5.6	59.9	37.0	2.6	26.1
PB0001	11.3	32.4	15.6	2.6	26.1
PB0014	11.3	31.4	10.7	2.3	26.1
PC0001	11.3	40.9	15.6	2.6	30.5
PC0002	22.6	26.9	14.8	2.3	30.5
PC0003	14.1	29.9	14.8	7.7	34.8
PC0004	16.9	25.0	14.0	5.1	43.5
PC0006	45.1	29.9	17.3	2.6	56.6
PC0008	42.3	26.9	14.8	2.6	43.5
PC0010	39.5	29.9	14.0	2.6	43.5
QB0001	11.3	19.0	8.2	2.6	17.4
QB0002	14.1	32.9	18.1	2.6	26.1
QC0017	39.5	39.9	25.5	2.6	30.5

QC0019	25.4	46.9	32.1	5.1	34.8
QC0023	31.0	64.9	41.2	2.6	47.9
QC0024	33.8	25.9	15.6	2.6	39.2
QC0025	8.5	54.9	38.7	2.6	26.1
QC0026	8.5	54.9	35.4	2.6	26.1
QC0027	11.3	37.4	20.6	2.6	21.8
QC0028	11.3	44.9	30.5	2.6	21.8
QC0029	19.7	42.4	34.6	2.6	30.5